Modification of the VSV Surface Pasteurizer to Treat the Visceral Cavity and Surfaces of Chicken Carcasses

M. KOZEMPEL, N. GOLDBERG, E.R. RADEWONUK, AND O.J. SCULLEN

ABSTRACT: Previous research with the VSV (vacuum/steam/vacuum) surface pasteurizer revealed the visceral cavity of chicken carcasses was not treated as effectively as the outside surface. The processor was modified to specifically treat the cavity by adding a mandrel assembly. Optimum process parameters were determined. Optimum process conditions were: initial vacuum 0.1 s, final vacuum 0.5 s, vacuum absolute pressure of 4.1 to 7.1 kPa, steam time 0.1 s, and steam temperature 138 °C. Using carcasses inoculated with *Listeria innocua* and the whole bird rinse sampling procedure, bacteria kills were statistically significant at 0.7 to 0.8 log cfu/mL. Using deboned chicken breasts inoculated with *L. innocua* and the whole bird rinse sampling procedure, bacteria kills were statistically significant at 1.0 to 1.3 log cfu/mL.

Keywords: surface pasteurization, chicken, APC, *Listeria, E. coli*

Introduction

BACTERIA ARE NOT NORMALLY PRESENT IN THE INTERIOR OF healthy, fresh chicken meat. Bacteria are in the pores and crevices of the flesh and skin on the surface of chicken flesh (Gill and Penney 1977). Some of the bacteria are nonpathogenic, spoilage organisms and some are pathogenic. Typical pathogens are *Salmonella, Campylobacter,* and *Listeria* (Anon. 1998a, 1998b). They can, and do, cause gastrointestinal distress in normal, healthy people. Except for the young, old, and immunosuppressed individuals, these organisms do not cause life-threatening disease.

Most bacteria are thermally sensitive and readily killed with heat. However, heating to reduce the population to safe levels without causing thermal damage to the associated chicken is the real challenge. The energy of activation required to deactivate vital enzymes in bacteria, sufficient to kill the bacteria, is on the order of 2 to 12 kcal/mol. The energy of activation required for irreversible muscle damage is 50 to 100 kcal/mol (Harper 1976). Theoretically, if the surface were heated quickly enough, only the bacteria would be affected, and there would be no thermal damage to the carcass.

Surface tension restricts liquids from entering pores and crevices on the surface of chicken flesh and skin. As Morgan discussed (Morgan and others 1996a), a gas treatment avoids this problem. Gas molecules are about 2×10^{-4} μm in dia with a mean free path of 0.4 μm at 140 °C, whereas bacteria are approximately 0.7 μm by 4 μm. Therefore, a gas can enter any cavity large enough to contain bacteria.

Condensing steam is a gas, which facilitates rapid energy transfer. However, air at the surface acts as insulation (Perry and others, 1984; Morgan and Carlson 1960). A simple steam pasteurization process of sufficient duration to kill these pathogens would thermally damage the meat. Therefore, a process called vacuum/steam/vacuum (VSV) surface pasteurization was developed that employs a short exposure to vacuum to remove insulating fluids. This is followed by a quick burst of steam. Then a second exposure to vacuum evaporatively cools the meat. The process is intended as an additional intervention step or hurdle in the processing of poultry.

A prototype surface pasteurizer was designed, fabricated, and patented (Morgan 1994; Morgan and others 1996a). Experiments utilizing this prototype showed the process reduces bacteria on fresh, raw chicken pieces about 2 to 3 log, depending on the type of piece (Morgan and others 1996b). For example, bacterial kills were greater on drumsticks than on breast meat.

Further research led to improved prototypes. Feasible process conditions were developed and verification experiments performed in cooperation with industry using the latest unit. These tests and follow-up experiments showed the visceral cavity was a problem and not treated as effectively as the outside surface (Kozempel and others 2000).

For example, in a series of tests with whole chicken carcasses exiting the chill tank from a federally inspected processing plant, control and treated samples were analyzed for total aerobic plate count (APC) with the whole bird rinse test. There was no statistically significant reduction in bacteria in the test. The controls averaged 3.0 log cfu/mL (SD = 0.29). Treated samples at 144 °C for 0.2 s had average counts of 3.3 log cfu/mL (SD = 0.48). At 149 °C for 0.15 s, the counts averaged 2.7 log cfu/mL (SD = 0.40), and at 154 °C for 0.05 s, the counts averaged 3.0 log cfu/mL (SD = 0.42). Although these were preliminary experimental conditions, the results indicated the cavity was not treated (Kozempel and others 2000).

The objective of this research was to develop modifications or improvements to the VSV surface pasteurizer to treat specifically the visceral cavity. We hypothesize that the addition of a mandrel assembly to the test chamber to specifically treat the chicken visceral cavity will kill bacteria in the cavity.

Materials and Methods

Mechanical Design of the VSV Surface Pasteurizer

The surface pasteurizer was designed to process chicken carcasses, specifically broilers. The performance requirements of a surface pasteurizer for chicken are to accept car-

casses individually and to enclose them in a chamber within a rotor; to evacuate that chamber; to inject saturated steam into the chamber containing the carcass; to draw vacuum on the chamber to evaporatively cool the carcass; and finally, to eject the carcass into a clean environment. The simplest configuration, 1 chamber in 1 rotor, was designed and constructed. Figure 1 shows a schematic diagram of the processor, and Figure 2 shows details of the product treatment section without the modifications of a mandrel presented here. A cylindrical chamber for a broiler carcass should be about 200-mm in dia, 240-mm deep. Such a chamber is formed within the wall of an 8-in ball valve.

To admit vacuum or steam into the closed chamber, 2 opposed 200-mm holes were bored through the ball valve stator (housing) at right angles to both the axis of rotation of the ball and to the centerline of the open chamber (carcass entry and exit ports) as shown in Figure 2. Two platter valves are close coupled to these 200-mm ports. Each consists of a flat disk rotating against an inlet header, which holds polyetheretherketone seals. Each disk contains 2 holes. When the disk is aligned with the ports in the inlet header, gas flows into or out of the treatment chamber. Multiple holes reduce the disk angular movement necessary for valve action and increase the cross-sectional area for gas flow. Each disk and mandrel is programmed independently and moved by its own servomotor. The servos are by Allen-Bradley Co., Inc. (Mayfield Valley, Ohio, U.S.A.) and are capable of high acceleration and deceleration. The servos for the disks are model 1326AB-C4B-11, 5.6 kW capable of 1600 rpm maximum. The servo for the mandrel is model 1326AB-B2E-11, 2.5 kW capable of 3000 rpm maximum. The servos are direct coupled mechanically to the disks and mandrel. Operation of the servos was controlled by Graphics Motion Language (GML) software version 3.8.2 (Allen-Bradley Co.). The GML program controlled the vacuum and steam times. Data acquisition was by Laboratory Technologies Corp. (Lab Tech Notebook version 8.04; Wilmington, Mass., U.S.A.). Sensors were by Omega Engineering, Inc., (Stamford, Conn., U.S.A.). Type E thermocouples were used for temperature, and Omega PX176 series sensors were used for vacuum and for steam pressure.

Vacuum was supplied by a reciprocating piston pump (type 30, model V67X5; Ingersol-Rand, New York, N.Y., U.S.A.). The steam generator was fabricated in-house. It was 115 l, horizontal submerged coils with no separator, 17.8 kW

heaters. The steam generator was charged with deionized water that was boiled for 30 min for deaeration. The vacuum receiver was adjusted to 7.1 kPa, and its condenser coil cooled to 4 °C.

The VSV Surface Pasteurizer Operation

Each sample was manually inserted into the treatment chamber of the surface pasteurizer. The ball valve was rotated, with a servo, 90 degrees to seal the chamber from the outside atmosphere. Operation of the ball valve was computer controlled. The platter valves rotated to expose the sample to a cycle of vacuum, steam, and vacuum, each applied for a predetermined time duration. After treatment, the ball valve rotated back 90 degrees to expose the sample to atmosphere. Samples were aseptically removed manually after treatment. Process variables studied were the initial and final vacuum times, the vacuum absolute pressure, steam temperature and time, and the number of cycles.

Modifications

To specifically treat the visceral cavity, a mandrel assembly was added to the product treatment valve as illustrated in Figure 3. The assembly includes a mandrel treatment valve body, a mandrel treatment valve rotor, seals, and a servo. The mandrel was connected to steam and vacuum through a hollow 2.5-cm stainless-steel tube. The tube passes through the product valve rotor and body coaxial to the axis of rotation of the product valve rotor. A tube seal prevents leakage between the product valve chamber and the environment. The hollow tube and mandrel are locked to the product valve rotor. All components were designed to minimize superheat.

Several mandrels were fabricated. The mandrels were mounted one at a time within the treatment chamber to test treatment of the cavity. Mandrels were fabricated of stainless steel. They were designed to conform approximately to the shape of the carcass cavity. Each contained holes or slots to facilitate effective transfer of air (vacuum) or steam in and out of the cavity during treatment. The vacuum or steam transfer through the mandrel was in addition to vacuum and steam entering through the platter valves as before. Initially, there were 7 mandrels. After the first few experiments, some of the mandrels were rejected as inferior. Two were clearly better than the others. The 2 were labeled II and III. Later some more mandrels were made, and a third mandrel chosen, identified as X. Figure 4 shows the 3 mandrels that proved to be the most effective.

Chicken Samples Testing

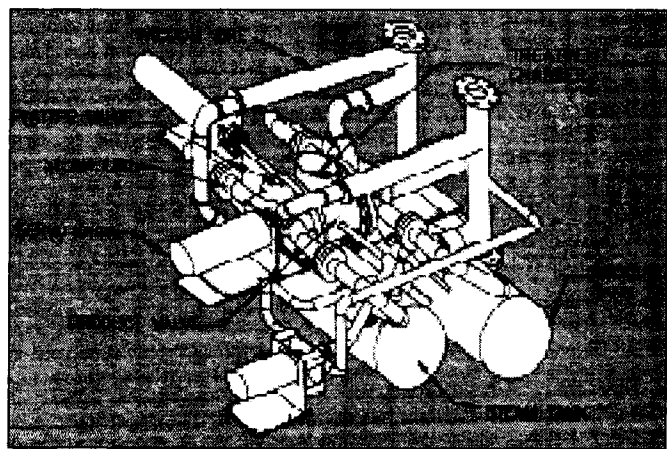Chicken (Cornish hens, broilers, or deboned chicken

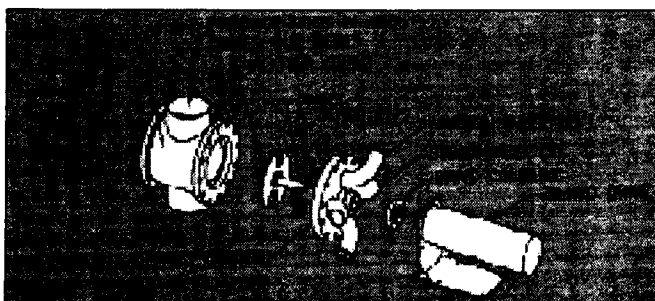Figure 1—Schematic diagram of the prototype VSV surface pasteurizer

Figure 2—Exploded view of 1 of the 2 platter valves on the prototype VSV surface pasteurizer

Table 1—Test of 2 sides of a carcass as control

		APC, log cfu/mL				
		Cavity		Outside		H_o^a
Sample	n	Difference	S.D.	Difference	S.D.	p
Control	10	0.03	0.315	-0.16	0.339	accept 0.2248
Splits, treated	64	0.59***	0.569	0.88***	0.477	reject 0.0025

[a]Null Hypothesis, | Difference cavity = Difference outside |
Significant differences represented by; *p ≤ 0.05 ** p ≤ 0.01 *** p ≤ 0.001.
n = number of tests

Table 2—Comparison of 2 mandrels using native flora

		APC, log cfu/mL				
		Cavity		Outside		H_o^*
Mandrel	n	kill	S.D.	kill	S.D.	p
II	58	0.71***	0.554	1.18***	0.509	reject 0.0001
III	14	0.37***	0.373	1.05***	0.675	reject 0.0019

[a]Null Hypothesis, | Kill cavity = Kill outside |
Significant differences represented by; p ≤ 0.05 ** p ≤ 0.01 *** p ≤ 0.001.
n = number of tests

breasts) was purchased at local supermarkets. Cornish hens and broilers were used whole or cut in half from breech to neck. Deboned chicken breasts (cutlets) were used whole.

For those experiments in which the chicken samples were inoculated, *Listeria innocua* (SA3-V-T; Buchanan and others 1991) was chosen as the inoculum because it is nonpathogenic and has similar or higher thermal resistance compared to *Listeria monocytogenes* (Ryser and Marth 1999). A loopful of *L. innocua* from a refrigerated slant was placed in 100 mL brain-heart infusion broth (BHI; Difco Laboratories, Detroit, Mich., U.S.A.) supplemented with 3% glucose. The addition of 3% glucose gave a higher cell density for inoculating the carcasses. The inoculum was incubated overnight at 28 °C. The carcasses were inoculated by immersion in a suspension of 10^6 cfu/mL *L. innocua* for 10 min. Specifically, a 10^9 cfu/mL *L. innocua* culture was dispersed in water (either 100 mL/19 l or 200 mL/38 l) to get a 10^6 cfu/mL suspension. The carcasses were allowed to drain in ambient conditions for 30 min before experimentation. The amount of inoculum, contact, and drain times had been previously determined by trial and error to allow sufficient bacteria to attach to the carcass. Inoculated carcasses had nominal bacteria counts of 4 to 5 log cfu/mL.

Broilers and Cornish hens were used interchangeably depending upon the availability at the supermarket. It would be preferable to use chicken carcasses as is, with the native flora as the test organism. It would be a truer test because the bacteria would presumably exist on the surface as they would in the process plant. However, the bacteria counts for *Salmonella, Campylobacter, Listeria,* and *E. coli* were generally too low to measure any appreciable change. Only the total aerobic plate count was sufficiently high to detect change.

For the data in Table 1, uninoculated broilers were used to test the hypothesis that the 2 sides of a carcass represent a good control, and both broilers and 5 Cornish hens were used for the splits. For the data in Table 2, which compared 2 of the mandrels, 17 broilers and 47 Cornish hens were used for mandrel II and 14 broilers for mandrel III.

During the course of the study, the average APC for fresh chicken purchased at the supermarket improved to less than 2.5 log cfu/mL. With a S.D. for APC on raw chicken carcasses ranging from of 0.3 to 0.5, we decided to discontinue using APC as an indicator; so, the research switched, after the results presented in Tables 1 and 2, to samples inoculated with *L. innocua*, a nonpathogenic indicator. This eliminated the uncertainty of low initial counts. Therefore, inoculated broilers were used for comparing mandrels in Table 3. Inoculated chicken cutlets were used for the factorial designs of Tables 4 to 6, which were performed without a mandrel.

Carcass Treatment

After inoculation, the chicken samples, whole carcasses or cutlets, were permitted to air dry at ambient conditions for 30 min. Each sample was handled individually. For whole carcasses, each carcass was swabbed on the left side, 1 swab for the outside and another swab for the cavity. These con-
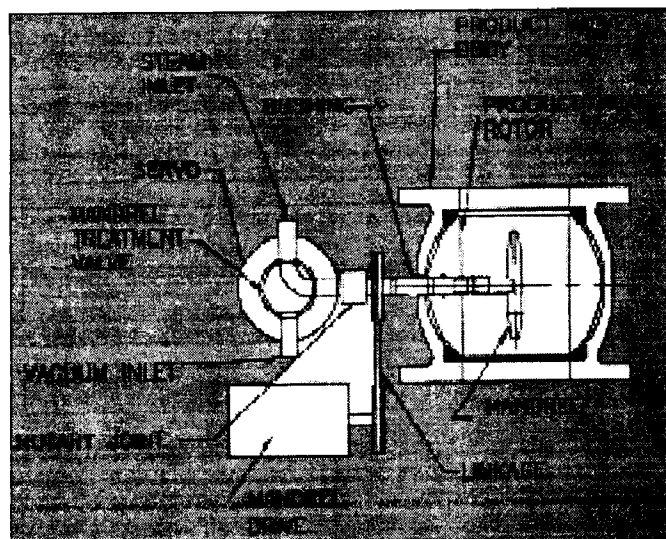

Figure 3—The mandrel assembly installed on the prototype VSV surface pasteurizer
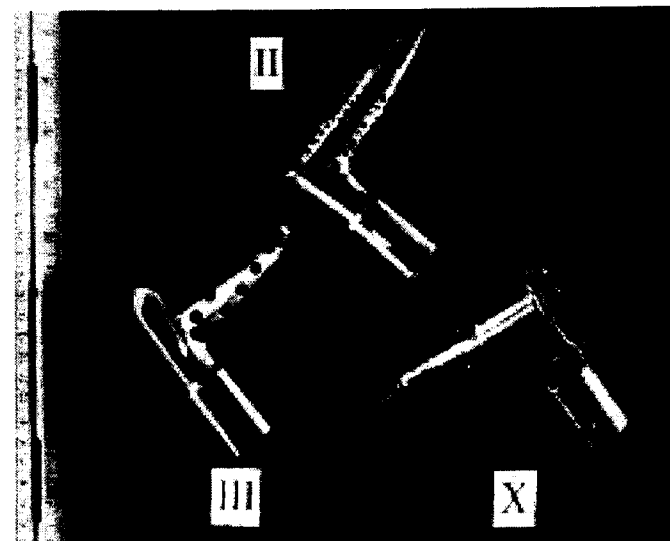

Figure 4—The 3 mandrels that were most effective

Table 3—Mandrel comparison with inoculated broilers

			Listeria innocua, log cfu/mL					
		Cavity			Outside			H₀ᵃ
Mandrel	n	kill	S.D.	n	kill	S.D.	p	
II	26	0.17*	0.329	26	0.93***	0.269	reject	0.0001
III	25	0.31***	0.251	25	0.89***	0.336	reject	0.0001
X	27	0.25***	0.190	29	0.88***	0.279	reject	0.0001
		Whole bird						
Mandrel	n	kill	S.D.					
II	30	0.72***	0.214					
III	30	0.70***	0.186					
X	60	0.79***	0.232					

ᵃNull Hypothesis, | Kill cavity = Kill outside |
Significant differences represented by; $p \leq 0.05$ ** $p \leq 0.01$ *** $p \leq 0.001$.
n = number of tests

Table 4—2³ experimental design and ANOVA using chicken cutlets with the temperature range extended to 143 °C

	−	+
A	138 °C	143 °C
B	0.3 s	0.5 s
C	6.2 kPa	4.1 kPa

A = steam temperature
B = final vacuum time
C = vacuum, absolute pressure
Initial vacuum = 0.1 s; Steam residence time = 0.1 s

Source	_L. innocua_, Log cfu/ml Mean square	F
A	0.0009	0.01
B	0.1639	1.54
C	0.1526	1.43
ERROR	0.1064	

Significant differences represented by; *$p \leq 0.05$ ** $p \leq 0.01$ *** $p \leq 0.001$

Control	Treatment
Mean = 4.72 log cfu/mL	Mean = 3.39
S.D. = 0.1775	S.D. = 0.312
n = 4	n = 64

Kill = 1.33 log cfu/mL.***

stituted the controls for each carcass. Then the carcass was aseptically and manually placed in the treatment chamber on the mandrel. The carcass was subjected to the VSV treatment. When the treatment was completed, the carcass was aseptically and manually removed from the treatment chamber. The right side was swabbed, 1 swab for the outside and 1 for the cavity. These constituted the treatments for each carcass. The carcass was disposed in accordance with Center established protocol.

After inoculation and drying, the cutlets were handled differently because they were not subjected to mandrel treatment and were assayed using the whole-bird rinse procedure. Each sample was handled individually. A treatment sample was aseptically and manually placed in the treatment chamber on a screen installed at the midpoint of the treatment chamber. The sample was subjected to the VSV treatment. When the treatment was completed, the sample was aseptically and manually removed from the treatment chamber. The chicken cutlet was placed in a sterile plastic bag, Butterfield solution added, and the sample assayed using the whole bird rinse procedure. The cutlet was disposed in accordance with Center established protocol. Controls were handled identically except they were not exposed to the VSV treatment.

The extent of cooking or thermal damage was visually judged subjectively immediately after treatment. The onset of cooking was obvious, marked by the whitening of the exposed flesh or shrinkage of the skin.

Microbiology Samples

After processing, 2 sampling techniques were used depending upon the objectives of the experiment. In the whole bird rinse procedure, samples were placed in sterile plastic bags (Nasco Poultry Rinse Bag, Ft. Atkinson, Wis., U.S.A.) with Butterfield buffer solution (Difco Laboratories) and manually rinsed for 60 s; 400 mL of buffer was used for a whole chicken and 200 mL for chicken halves and chicken cutlets. Aliquots of uninoculated samples were plated on aerobic count plate 3M Petrifilm™ (3M Microbiology Products, St. Paul, Minn., U.S.A.) for APC and on _E. coli_ count plate Petrifilm for determining coliforms and _E. coli_. Samples were plated in triplicate (Cox and others 1981). Aliquots of inoculated samples with _L. innocua_ were plated on TA plates using the spiral plating system (Spiral Systems Instruments, Inc., Bethesda, Md., U.S.A.). The plates were then incubated at 37 °C for 18 to 24 h, and the survivors were enumerated using a laser bacteria colony counter model 500A (Spiral Sys-

tems).

The sponge method (Palumbo and others 1999) was used for experiments in which the cavity was studied separately from the exterior surface. A sterile sponge from a Whirlpack™ bag dampened with 10 mL of Butterfield buffer was used to swab either the left or right side of either the exterior surface or the cavity of a carcass. The sponges were maintained at cold temperature during the experiment. After the experiment was completed and all samples taken, they were immediately analyzed. After the addition of 90 mL of Butterfield buffer, the sponge samples were mixed for 1 min at normal speed using a stomacher (Stomacher 400; Tekman, Cincinnati, Ohio, U.S.A.). The sponge samples were serially diluted with 0.1% peptone water (Difco Laboratories) for _E. coli._, APC, and _L. innocua._

E. coli plate counts were obtained, in triplicate, using _E coli_ count plate Petrifilm following the manufacturer's recommended procedures. The total aerobic counts were obtained on the serially diluted sponge samples using Aerobic count plate Petrifilm following the manufacturer's recommended procedures. The Petrifilms were manually counted after incubation at 37 °C for 48 h. Serially diluted sponge samples for _L. innocua_ were plated onto TA plates using the spiral plating system. The plates were incubated at 37 °C for 18 to 24 h. Survivors were counted using the laser bacteria counter. Samples were plated in triplicate.

Control samples were difficult to establish but were necessary to evaluate the effects of equipment modifications on treatment of the cavity. It was assumed that the 2 sides of an individual carcass would present the closest matching samples so that 1 could be used as a control sample. To determine if the counts for the cavity and the outside surface would be different and respond differently to treatment, the sponge method of analysis was used. The sampling method was the same for APC and for _L. innocua._ The left side of the carcass, cavity and outside, were sampled separately, before treatment, for control. The right side, cavity and outside, were sampled separately after treatment for the test samples.

Splits were used to compare response to treatment of the fully exposed cavity in contrast to the outside surface. The splits were carcasses that were split in half lengthwise, and the 2 sides sampled, before and after treatment. This permitted us to evaluate the susceptibility to treatment of the cavity wall exposed externally and the outside carcass surface.

Table 5 – 2³ experimental design and ANOVA using chicken cutlets with steam time increased to 0.2 s

		−	+
A		0.1 s	0.2 s
B		0.1 s	0.5 s
C		6.2 kPa	4.1 kPa

A = steam time
B = final vacuum time
C = vacuum, absolute pressure
Initial vacuum = 0.1 s
Steam temperature = 138 °C

Source	L. innocua Log cfu/ml Mean square	F
A	0.1152	1.51
B	0.8128	10.62**
C	0.0365	0.48
Error	0.07651	

Significant differences represented by; *$p \leq 0.05$ ** $p \leq 0.01$ ***$p \leq 0.01$

Control	Treatment
Mean = 4.98 log cfu/mL	Mean = 3.86
S.D. = 0.170	S.D. = 0.327
n = 8	n = 64

Kill = 1.12 log cfu/mL***

Table 6 – 2³ experimental design and ANOVA using chicken cutlets and the lower temperature extended to 127 °C

		−	+
A		0.1 s	0.2 s
B		0.1 s	0.5 s
C		6.2 kPa	4.1 kPa

A = steam time
B = final vacuum time
C = vacuum, absolute pressure
Initial vacuum = 0.1 s
Steam temperature = 127 °C

Source	L. innocua Log cfu/ml Mean square	F
A	0.2415	3.80
B	0.0903	1.42
C	0.0421	0.66
Error	0.06351	

Significant differences represented by; *$p \leq 0.05$ ** $p \leq 0.01$ *** $p \leq 0.01$

Control	Treatment
Mean = 4.73 log cfu/mL	Mean = 3.75
S.D. = 0.198	S.D. = 0.327
n = 8	n = 64

Kill = 0.98 log cfu/mL***

Bacteria inoculated on the surface of both cavity and outside surfaces probably respond differently from bacteria naturally present. Total APC naturally present was used for the data in Tables 1 and 2. For the data presented in Tables 3 to 6, the APC was too low so the chicken was inoculated.

Statistical Methods

For Tables 1 to 3, a null hypothesis was made (Volk 1958) on the difference between the mean bacteria kills and 0 (H_o; mean = 0) or between means (H_o; mean$_1$ = mean$_2$). For optimization studies presented in Tables 4 to 6, 2³ factorial experimental designs (Davies and others 1960) were used. Treatment samples consisted of 4 replicates. The data from the factorial designs were analyzed by analysis of variance using the replicate within treatment terms as error terms. The results in Tables 4 to 6 were without the mandrel. Control samples of untreated carcasses were taken to provide an estimate of the extent of bacteria kill.

Results and Discussion

Mandrel Modification

To test the hypothesis that the 2 sides of a carcass can be used as a control to compare treatment in contrast to no treatment, 10 carcasses were analyzed with the sponge method. The left side of a carcass was sampled without treatment for control. The right side was sampled, also without treatment, for the test samples. With no treatment, there should be no difference for either side. The first row of Table 1 lists the results. A null hypothesis showed that the difference between the 2 sides was not significantly different from 0.

There is still the question of different responses by the outside surface and the cavity. In our previous work, tentative optimum process conditions found were 0.1 s initial vacuum, 0.1 s steam at 138 °C, and 0.5 s final cooling vacuum. These process parameters were the default conditions used for all tests except where other conditions are explicitly stated. The 2nd row of Table 1 lists the results comparing treatment with exposed cavities (splits). There was a highly significant kill for the outside and the cavity, but a null hypothesis indicated there was a significant difference in the kill on the 2 surfaces. The cavity had less kill, 0.6 in contrast to 0.9 log cfu/mL APC for the outside surface. The initial mean APC

count for the cavity was 2.53 log cfu/mL and for the outside was 2.83 log cfu/mL.

Two of the mandrels (II and III) were tested at the tentative, optimum process conditions for effectiveness treating the cavity and outside surface. (Mandrel X had not been conceived yet.) The left side of the carcass was sampled without treatment for control. The right side was sampled, after treatment, for the test samples. The results are shown in Table 2. Sponge analysis was used. There were highly significant kills for both surfaces. A null hypothesis indicated there was a significant difference between the cavity and the outside surface for both mandrels. There was no significant difference between the 2 mandrels (p = 0.4584) in kill on the outside surfaces. But, for the cavity, there was a significant difference (p = 0.0025) between the mandrels. Mandrel II was better than mandrel III.

The APC for the untreated controls were 4.11 and 4.38 log cfu/mL, respectively, for the cavity and the carcass outside surfaces for mandrel II tests. For mandrel II, the values after treatment were 3.40 and 3.21.

The previous experiments were repeated using inoculated carcasses, inoculated to about 4.5 log cfu/mL *L. innocua*, and evaluated using the sponge test. The left side of the carcass was sampled without treatment for control. The right side was sampled, after treatment, for the test samples. Table 3 lists the results. There was a significant reduction in bacteria in all cases. The cavity treatment was significantly less effective than treatment of the outside surface. Using a null hypothesis, there was no statistical difference between the mandrels.

A more realistic test of the process will be carried out at commercial plants using the whole bird rinse method of analysis. The experiments were duplicated using the whole bird rinse method of determining bacteria counts. Table 3 shows that all 3 mandrels gave significant kills of 0.7 to 0.8 log cfu/mL *L. innocua*. Based on these results, we conclude that the mandrel modification will treat the visceral cavity.

Unfortunately, there are limitations to using the mandrels in the current unit. The present mandrel is fixed. It rotates to the horizontal when the ball valve closes. This reduces the effectiveness of the mandrel because the carcass tends to slide partially off the mandrel, exposing the base of the mandrel. Also, the steam and vacuum ports are smaller than in the platter valves.

Another unit has been designed and fabricated for field tests at poultry processing plants. This design employs a mandrel that does not rotate with the ball valve. It will remain vertical inside the carcass visceral cavity. The steam and vacuum ports more closely match the ports in the platter valves. Field tests were scheduled to begin in the year 2000.

Optimization

In preparation for field tests, experiments were made to confirm the optimum process conditions. In the current unit, the cavity can be treated but not as effectively as the outside surface. Therefore, research was continued using deboned chicken breasts (chicken cutlets). This eliminated interference from the cavity.

Starting with the tentative, optimum process conditions of 0.1-s initial vacuum, 0.1-s steam at 138 °C, and 0.5-s final cooling vacuum, a series of 2^3 factorial designs were made. In the first design, the temperature range was extended to 143 °C to determine if there were better kills. A final vacuum of 0.1 s is too short to sufficiently and evaporatively cool the surface after treatment. This time was shortened to 0.3 s from 0.5 s to determine if the full 0.5 s was necessary. The third variable was the level of the vacuum, kPa. By using a different vacuum source, this was improved slightly to 4.1 kPa absolute pressure.

Table 4 lists the results of the design. All samples were inoculated with L. innocua. No variable gave a significant response. The mean of all treatments was 3.39 log cfu/mL (SD = 0.312). The mean of the 4 control samples was 4.72 log cfu/mL (SD = 0.178). The mean kill was 1.33 log cfu/mL. The thermal damage to the meat was prohibitive at 143 °C but not at 138 °C.

The next design was similar. Instead of steam temperature, the steam time was increased to 0.2 s with the steam temperature held constant at 138 °C. The final vacuum time was further reduced to 0.1 s. At this final vacuum time, there was insufficient cooling. The vacuum levels were the same as in the previous design.

Table 5 lists the results. Final vacuum time was significant. The mean count for L. innocua at 0.5 s vacuum time was 4.02 log cfu/mL. At 0.1-s vacuum time, the count was 3.70 log cfu/mL. This confirmed our previous findings. Unfortunately, the surface was thermally damaged because of inadequate cooling. The mean of all treatments was 3.86 log cfu/mL (S.D. = 0.327). The mean of 8 control samples was 4.98 log cfu/mL (S.D. = 0.170). The mean kill was 1.12 log cfu/mL.

This design was repeated as shown in Table 6 at the lower temperature previously found to be in the optimum range, 127 °C. No variable was significant. The shorter final vacuum time failed to cool the sample sufficiently to prevent thermal damage. The mean of all treatments was 3.75 log cfu/mL (S.D. = 0.327). The mean of 8 control samples was 4.73 log cfu/mL (S.D. = 0.198). The mean kill was 0.98 log cfu/mL, slightly less than the mean using 138 °C (1.12 log cfu/mL).

The experimental data points from Tables 4 to 6 that corresponded to the optimum range (initial vacuum at 0.1 s, final vacuum at 0.3 to 0.5 s, steam temperature at 127 to 138 °C, and steam time at 0.1 s) were combined. The mean count for L. innocua at optimum treatment conditions was 3.66 log cfu/mL (SD = 0.401, n = 40). The mean count for L. innocua for the controls was 4.82 log cfu/mL (SD = 0.206, n = 36). The kill was 1.17 log cfu/mL.

Conclusions

THE ADDITION OF A MANDREL TO THE VSV SURFACE PASTEURizer successfully killed bacteria in the visceral cavity of chicken carcasses. Unfortunately, kills in the cavity, while statistically significant, were not very impressive. However, these results were obtained on a retrofitted unit. We anticipate results will be greatly improved with a new unit currently under development. Different surfaces on a carcass are treated unequally. Using deboned chicken breasts (chicken cutlets) to eliminate the effect of the cavity, new tests of the process parameters confirmed that the parameters previously found are near optimal.

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Authors are with the U.S. Dept. of Agriculture, ARS, ERRC, 600 East Mermaid Lane, Wyndmoor, PA 19038. Direct correspondence to author Kozempe (E-mail: mkozempel@arserrc.gov).